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SHORT PERIOD SIGNAL-TO-NOISE RATIO AT NORSAR

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Teledyne Geotech

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ABSTRACT

Analysis of nine events recorded by the NORSAR short-period array reveals that a beam of the ten Northeast subarrays has only .06 magnitude units less detection capability than the full array and that the 3C subarray has only .18 magnitude units less capability. We show that if the 3C subarray were expanded to 56 elements inside a 15 km diameter circle it would have .3 magnitude units more detection capability than the present full array.

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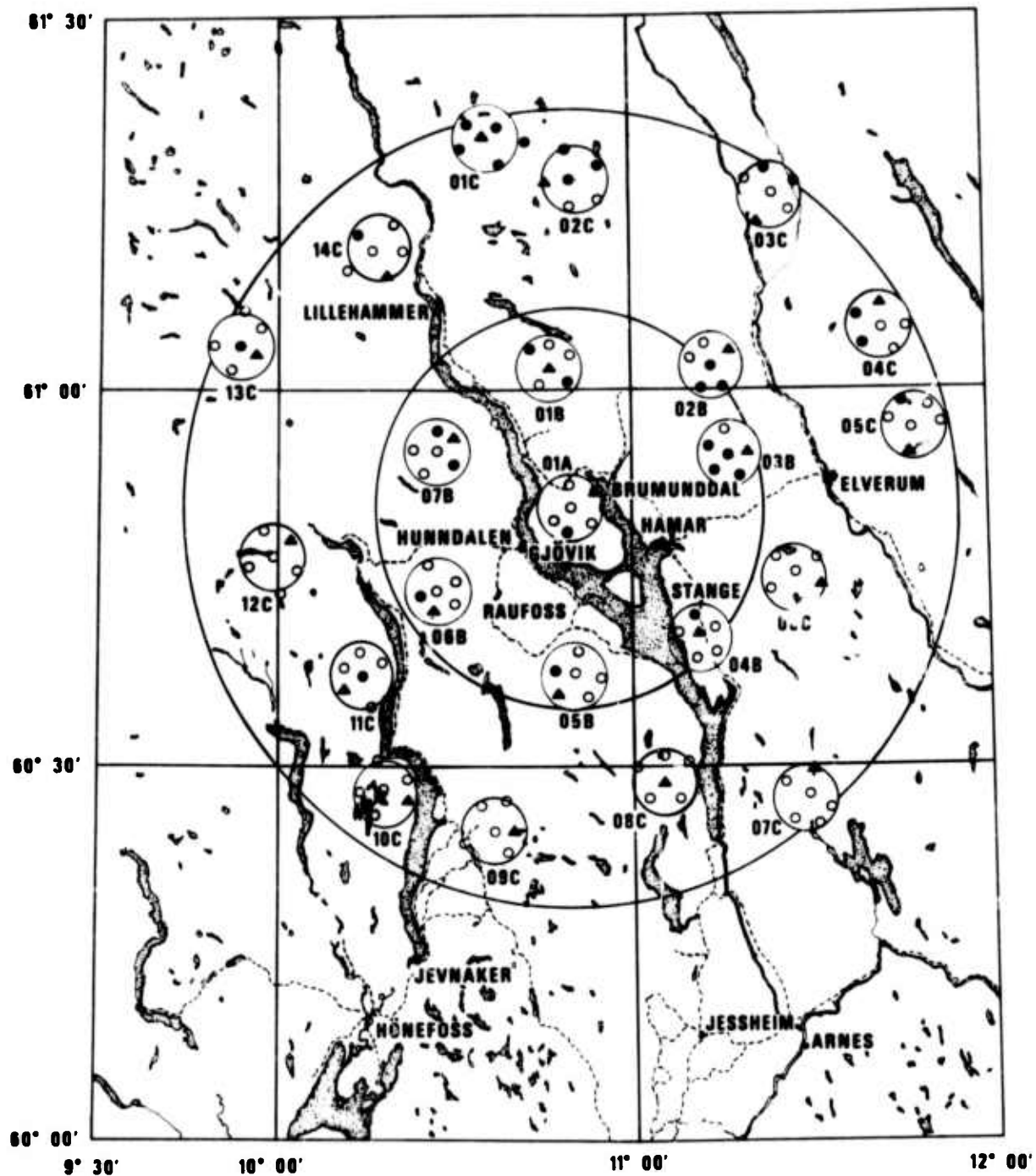
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INTRODUCTION

NORSAR is a combined short-period, long-period 22-subarray seismic array in Norway, depicted in some detail in Figure 1. Each subarray contains 6 short-period vertical instruments and one set of co-located Vertical, North, and East long-period instruments distributed within a 10 km diameter circle. Comprehensive evaluations of the short-period NORSAR array have been published by Felix, Gilbert, and Wheeler (1971), Barnard and Whitelaw (1972) and by Ringdal and Whitelaw (1973). These studies have covered such topics as variation of noise spectrum and rms noise level as a function of time, spectral content of noise and signal, optimal filtering, signal variation across the array; signal loss, noise reduction, and signal-to-noise gain in beamforming, detection threshold estimation, and performance of short-period discriminants at NORSAR.

The present study concentrates on the question: What subarrays and combinations of small numbers of subarrays will give a detection threshold as close as possible to that of the full array?



LEGEND

- ▲ LONG PERIOD INSTRUMENT, VAULT
- SHALLOW HOLE SP
- DEEP HOLE SP

----- MAJOR ROADS

Figure 1. Map of Norsar.

DATA

In Table I we list the nine events considered in this study. They have been chosen with attention to their distribution in distance and azimuth, and source regions of special interest have been included. In addition the event magnitudes have been chosen so that there is no clipping at the subarrays with the largest signal amplitudes. The event names are the same as those used by Barnard and Whitelaw (1972) and Ringdal and Whitelaw (1973).

In Figure 2 we see the 3C and 12C subarray beams for KAZ/145/04N. Each trace is shown unfiltered, filtered 0.4-3.0 Hz, and filtered 1.1-2.9 Hz. The two filters are 3-pole Butterworth filters created by program FILCOF.

We see from subarray 12C beams that the 1.1-2.9 Hz filter improves the signal-to-noise ratio, and from subarray 3C that the signal loss is only about 1.4 dB. Investigations by all of the authors cited in the Introduction to this report reveal that a filter pass band of about 1.0-3.0 Hz is optimum for detection. The present on-line filter for beamforming NORSAR data is a 3-pole Butterworth filter, 1.2-3.2 Hz. For incoherent beamforming the on-line filter is 1.6-3.2 Hz (Tveitane, 1973). We shall perform the analysis in this report solely with the 1.1-2.9 Hz filter.

TABLE I
EVENTS USED

EVENT		DATE	ORIGIN	LAT.	LON.	M _b	Δ	Az	DEPTH	TAPE	SUBSET TAPE	
KAZ	145	04N	5-25-71	04:02:57	49.8N	78.2E	5.2	38.0	75.4	0	13034	L07292
RYU	240	15N	8-28-71	15:57:48	28.3N	130.7E	5.7	78.5	51.2	35	15282	L08539
URA	191	16N	7-10-71	16:59:59	64.2N	55.2E	5.3	20.3	61.2	0	11095	L03502
IRA	221	02N	8-09-71	02:54:37	36.2N	52.7E	5.2	36.0	113.7	27	10227	L08296
TIB	123	00N	5-03-71	00:33:22	30.8N	84.5E	5.4	55.6	87.3	16	13261	L06401
KUR	213	02N	8-01-71	02:06:06	50.4N	156.8E	5.6	65.5	23.1	20	07181	L06583
SIN	207	01N	7-26-71	01:48:33	39.9N	77.2E	6.0	44.8	86.4	20	13336	L08276
NEV	230	14N	8-18-71	14:00:00	37.1N	116.0W	5.4	72.6	318.1	0	15277	L13185
GRE	109	02N	4-19-71	02:43:52	39.0N	20.5E	5.1	22.6	160.2	16	13233	L06770

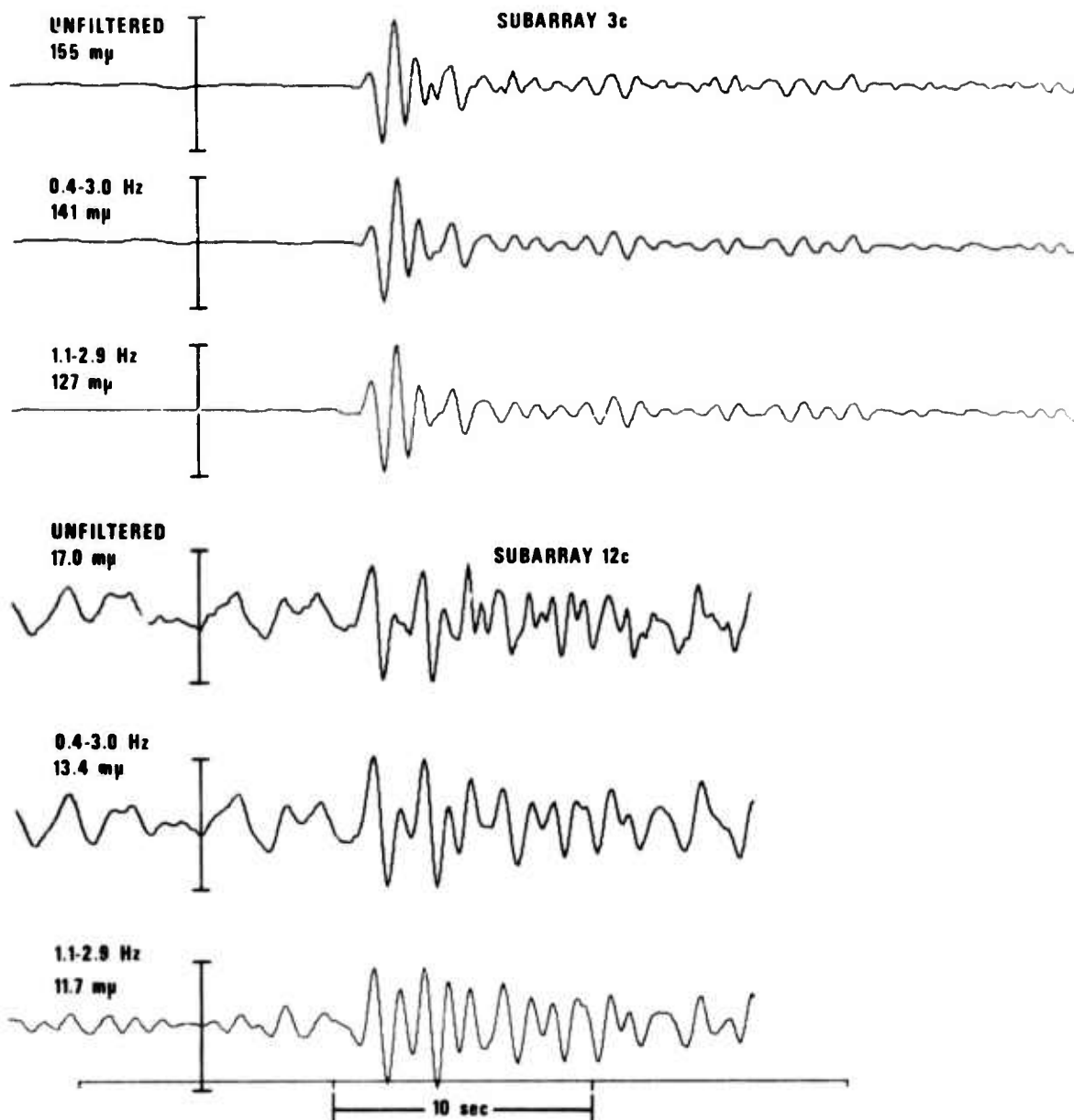


Figure 2. Subarray beams for KAZ/145/04N for subarrays 3C and 12C unfiltered, and filtered 0.4-3.0 and 1.1-2.9 Hz. Subarray 3C shows that there is very little signal loss, and subarray 12C shows the substantial gain in S/N.

SIGNAL AND NOISE PROPERTIES OF THE SUBARRAYS

Using program QUICSAN we filtered the output from each sensor and beamed each subarray using the azimuth and Herrin (1968) velocity appropriate for the event. In Table II we see the results for each subarray for each event. The signal values are the logarithm to the base 10 of half the maximum peak-to-peak subarray beam signal in millimicrons in the first 20 seconds of the signal. The noise values are the logarithm of the root-mean-square (rms) subarray beam noise in the 60 seconds preceding the signal. The signal-to-noise ratio (S/N) is the difference of these two.

In Figure 3 we see these three numbers contoured on a map of NORSAR for the event KAZ/145/04N. Note that the contour for large signal and the contour for small noise overlap for subarray 3C which has the largest S/N ratio. In Figure 4 we contoured the average logarithm of the noise on NORSAR beams for all nine events. We see that there is a maximum noise level running northwest-southeast through the center of the array; and by reference to Figure 1 we can see that it is associated with large bodies of water which, as might be expected, are correlated with high population density and cultural activity. The noisiest subarray, 14C, can be seen on a more detailed map to lie between two roads along which is the highest density of population on the map outside of a major town. Thus it would appear that the noise levels are cultural and can amount to as much as 0.1-0.2 magnitude units.

In Figure 5 we have contoured the average logarithm of the signals on NORSAR beams of all nine events. Arrows indicate the direction of arrival of the nine events. (Events from the Southwest come either from the mid Atlantic ridge or South America.) We see that subarray 3C is the best subarray; and that the northeast corner in general has high signal levels.

In Figure 6 we have contoured the "difference" of Figures 4 and 5 resulting in contours of S/N. Again we see that the northeast subarrays are superior.

In Figure 7 we have plotted the name of the event next to the subarray which had the highest S/N for that event. We see that the northeast subarrays are always the best, except for the RYU event, in which case subarray

TABLE IIa
Log₁₀ of Signal, Noise, and S/N by Subarray

EVENT	Log											
	S 1A	N 1A	S/N 1A	S 1B	N 1B	S/N 1B	S 2B	N 2B	S/N 2B	S 3B	N 3B	S/N 3B
KAZ/145/04N	1.37	-.18	1.55	1.49	-.28	1.74	1.43	-.31	1.75	1.57	-.14	1.71
RYU/240/15N	1.09	-.07	1.16	1.09	-.32	1.41	1.26	-.23	1.49	.94	-.14	1.08
URA/191/16N	1.73	-.27	2.00	1.84	-.27	2.11	1.97	-.24	2.21	1.96	-.30	2.26
IRA/221/02N	1.79	-.19	1.98	1.78	-.22	2.00	1.80	-.11	1.91	2.02	-.09	2.11
TIB/123/00N	1.50	-.14	1.64	1.36	-.22	1.58	1.71	-.27	1.98	1.74	-.19	1.93
KUR/213/02N	1.70	-.41	2.11	1.78	-.43	2.21	2.08	-.43	2.55	1.79	-.36	2.15
SIN/207/01N	1.92	.13	1.79	1.65	.00	1.65	1.85	.07	1.78	1.97	.04	1.93
NEV/230/14N	.72	-.20	.92				1.00	-.38	1.38	1.47	-.22	1.69
GRE/109/02N	1.55	-.03	1.58	1.43	-.12	1.55	1.57	+.02	1.55	1.55	-.03	1.58
Average	1.48	-.16	1.64	1.55	-.23	1.78	1.63	-.21	1.84	1.67	-.15	1.82

TABLE IIb
Log₁₀ of Signal, Noise, and S/N by Subarray

EVENT	Log											
	S 4B	N 4B	S/N 4B	S 5B	N 5B	S/N 5B	S 6B	N 6B	S/N 6B	S 7B	N 7B	S/N 7B
KAZ/145/04N	1.66	-.19	1.86	.83	-.27	1.10	1.04	-.29	1.11	1.16	-.28	1.43
RYU/240/15N	1.01	-.15	1.16	.90	-.14	1.04	.89	-.32	1.21	1.20	-.24	1.48
URA/191/16N	1.93	-.38	2.31	1.80	-.37	2.17	1.95	-.37	2.32	2.06	-.29	2.35
IRA/221/02N	1.70	-.16	1.86	1.69	-.07	1.76	1.84	-.19	2.03	1.41	-.21	1.62
TIB/123/00N	1.49	-.20	1.70	1.21	-.14	1.35	1.12	-.33	1.45	1.51	-.16	1.67
KUR/213/02N	1.59	-.38	1.97	1.55	-.35	1.90	1.77	-.48	2.25	1.39	-.40	1.79
SIN/207/01N	1.80	.01	1.79	1.84	-.02	1.86	1.45	-.08	1.53	1.89	.21	1.68
NEV/230/14N	.96	-.32	1.28	.54	-.35	.89	.63	-.34	.97	.78	-.29	1.07
GRE/109/02N	1.36	-.20	1.56	1.19	-.06	1.25	1.36	-.23	1.59	1.44	-.04	1.48
Average	1.50	-.22	1.72	1.28	-.20	1.48	1.34	-.26	1.60	1.43	-.19	1.62

TABLE IIc
Log₁₀ of Signal, Noise, and S/N by Subarray

EVENT	Log											
	S 1C	N 1C	S/N 1C	S 2C	N 2C	S/N 2C	S 3C	N 3C	S/N 3C	S 4C	N 4C	S/N 4C
KAZ/145/04N	1.31	-.37	1.68	1.26	-.40	1.66	1.79	-.42	2.23	1.83	-.25	2.07
RYU/240/15N	1.44	-.29	1.73	1.32	-.38	1.66	1.46	-.25	1.71	1.50	-.26	1.76
URA/191/16N	2.24	-.33	2.57	1.74	-.37	2.11	2.04	-.4	2.38	1.73	-.42	2.15
IRA/221/02N	1.36	-.19	1.55	1.62	-.23	1.85	1.57	-.33	1.90	1.88	-.31	2.19
TIB/123/00N	1.98	-.32	2.30	1.98	-.27	2.25	1.84	-.25	2.09	1.59	-.34	1.93
KUR/213/02N	1.95	-.34	2.29	1.92	-.45	2.37	2.07	-.48	2.55	1.91	-.51	2.42
SIN/207/01N	1.90	.18	1.72	1.81	.12	1.69				2.09	-.11	2.20
NFV/230/14N	.86	-.35	1.21	.80	-.36	1.16	1.20	-.38	1.58	.70	-.31	1.01
GRE/109/02N	1.37	-.21	1.58	1.19	-.26	1.45	1.49	-.09	1.58	1.58	-.20	1.78
Average	1.10	-.25	1.85	1.52	-.28	1.80	1.73	-.28	2.01	1.65	-.29	1.94

TABLE IId
Log₁₀ of Signal, Noise, and S/N by Subarray

EVENT	Log											
	S 5C	N 5C	S/N 5C	S 6C	N 6C	S/N 6C	S 7C	N 7C	S/N 7C	S 8C	N 8C	S/N 8C
KAZ/145/04N	1.48	-.24	1.72	1.85	-.22	2.07	1.42	-.29	1.72	1.23	-.17	1.39
RYU/240/15N	1.44	-.28	1.72	.88	-.31	1.19	1.04	-.28	1.32	.82	-.16	.98
URA/191/16N	1.90	-.29	2.19	2.10	-.37	2.47	1.91	-.50	2.41	1.79	-.32	2.11
IRA/221/02N	1.77	-.13	1.90	1.74	-.12	1.86	1.86	-.37	2.13	1.69	-.18	1.87
TIB/123/00N	1.99	-.26	2.25	1.39	-.24	1.63	1.64	-.29	1.93	1.40	-.11	1.51
KUR/213/02N	1.85	-.42	2.27	1.54	-.50	2.04	1.72	-.54	2.26	1.57	-.35	1.92
SIN/207/01N	1.88	.10	1.78	2.00	.11	1.89	1.89	-.03	1.92	1.46	.05	1.41
NEV/230/14N	.69	-.40	1.09	.93	-.28	1.26	.95	-.39	1.34	.80	-.20	1.00
GRE/109/02N	1.75	-.22	1.97	1.57	-.09	1.66	1.33	-.06	1.39	1.37	-.04	1.41
Average	1.64	-.26	1.88	1.56	-.22	1.78	1.53	-.29	1.82	1.35	-.16	1.51

TABLE IIe
Log₁₀ of Signal, Noise, and S/N by Subarray

EVENT	Log											
	S 9C	N 9C	S/N 9C	S 10C	N 10C	S/N 10C	S 11C	N 11C	S/N 11C	S 12C	N 12C	S/N 12C
KAZ/145/04N	.81	-.23	1.04	1.61	-.24	1.85	.95	-.23	1.17	.72	-.21	.93
RYU/240/15N	1.10	-.24	1.34	.92	-.26	1.18	1.23	-.25	1.48	1.13	-.29	1.42
URA/191/16N	1.81	-.28	2.09	1.65	-.35	2.00	1.81	-.40	2.21	2.17	-.38	2.55
IRA/221/02N	1.79	-.14	1.93	1.80	-.17	1.97	1.60	-.24	1.84	1.75	-.20	1.95
TIB/123/00N	1.44	-.38	1.82	1.86	-.32	2.18	1.49	-.31	1.80	1.76	-.33	2.09
KUR/213/02N	2.05	-.32	2.37	1.63	-.32	1.95	1.22	-.49	1.71	1.29	-.42	1.71
SIN/207/01N	1.65	.08	1.57	1.81	.21	1.60	1.50	-.08	1.58	1.92	-.11	2.03
NEV/230/14N	.78	-.22	1.00	1.00	-.21	1.21	.70	-.39	1.09	.69	-.33	1.02
GRE/109/02N				1.41	-.13	1.54	1.39	-.23	1.62	1.16	-.10	1.26
Average	1.43	-.21	1.64	1.52	-.20	1.72	1.32	-.29	1.61	1.40	-.26	1.66

TABLE IJf
Log₁₀ of Signal, Noise, and S/N by Subarray

EVENT	Log					
	S	N	S/N	S	N	S/N
	13C	13C	13C	14C	14C	14C
KAZ/145/04N	1.15	-.24	1.39	1.35	-.14	1.49
RYU/240/15N	1.44	-.36	1.80	1.05	-.11	1.26
URA/191/16N	1.90	-.40	2.35	2.02	-.11	2.13
IR V/221/02N	1.70	-.18	1.88	1.40	-.04	1.44
TIB/123/00N	1.69	-.25	1.94	1.41	-.18	1.59
KUR/213/02N	1.64	-.46	2.10	1.22	-.02	1.24
SIN/207/01N	1.69	.07	1.62	1.46	.24	1.18
NEV/230/14N	.89	-.37	1.26	.63	-.26	.89
GRE/109/02N	1.14	-.11	1.25	1.20	-.10	1.30
Average	1.47	-.26	1.73	1.30	-.09	1.39

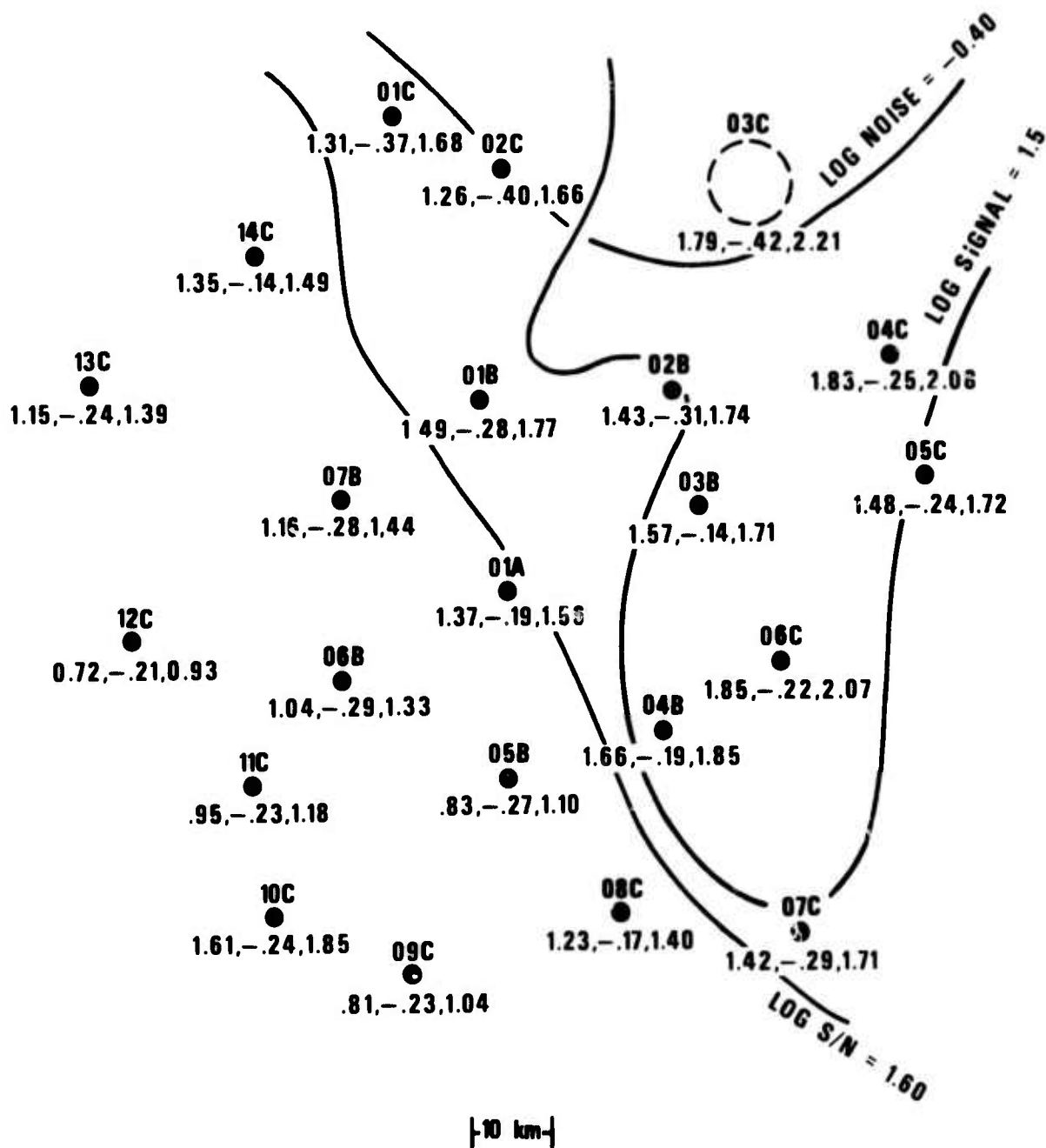


Figure 3. Signal, noise, and S/N for KAZ/145/04N. Circle at subarray 3C indicates size of the subarrays.

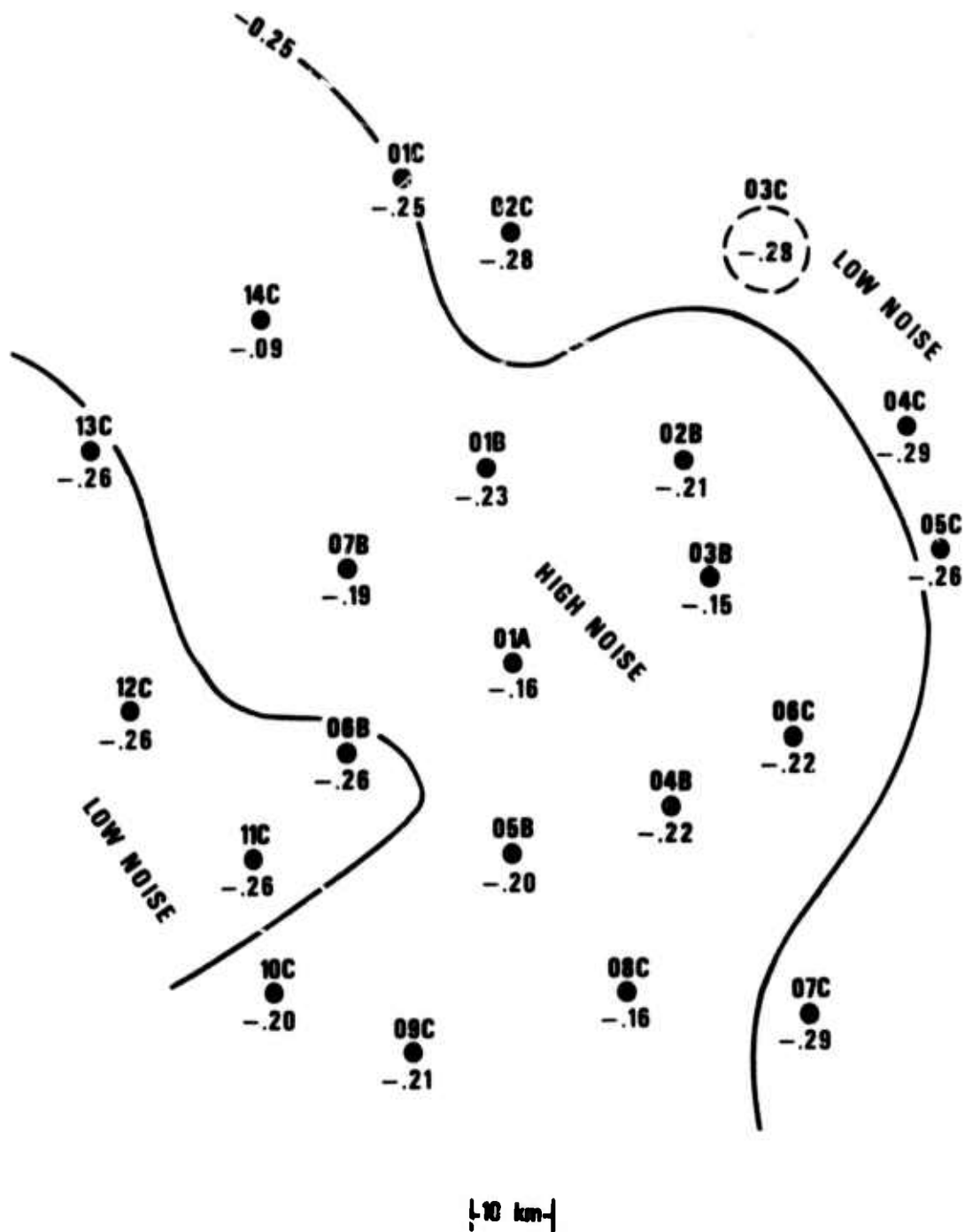


Figure 4. Log_{10} noise (rms, μV) averaged over 60 seconds of noise before events¹⁰ in Table I at each subarray. High noise levels correspond to heavily populated areas.

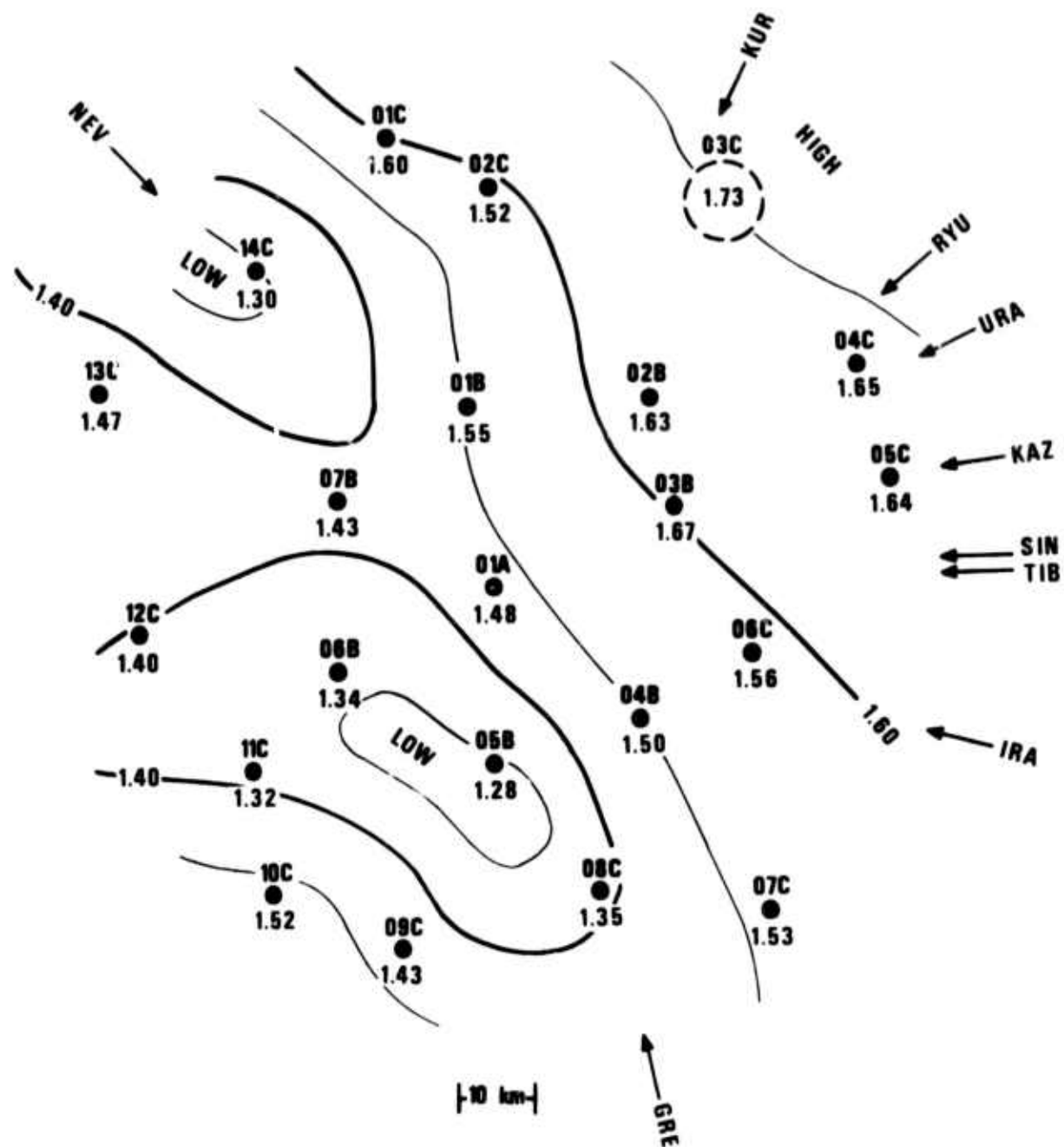


Figure 5. Log_{10} signal (O-P, $\text{m}\mu$) averaged over events in Table I at each subarray. Arrows indicate direction of arrival of events.

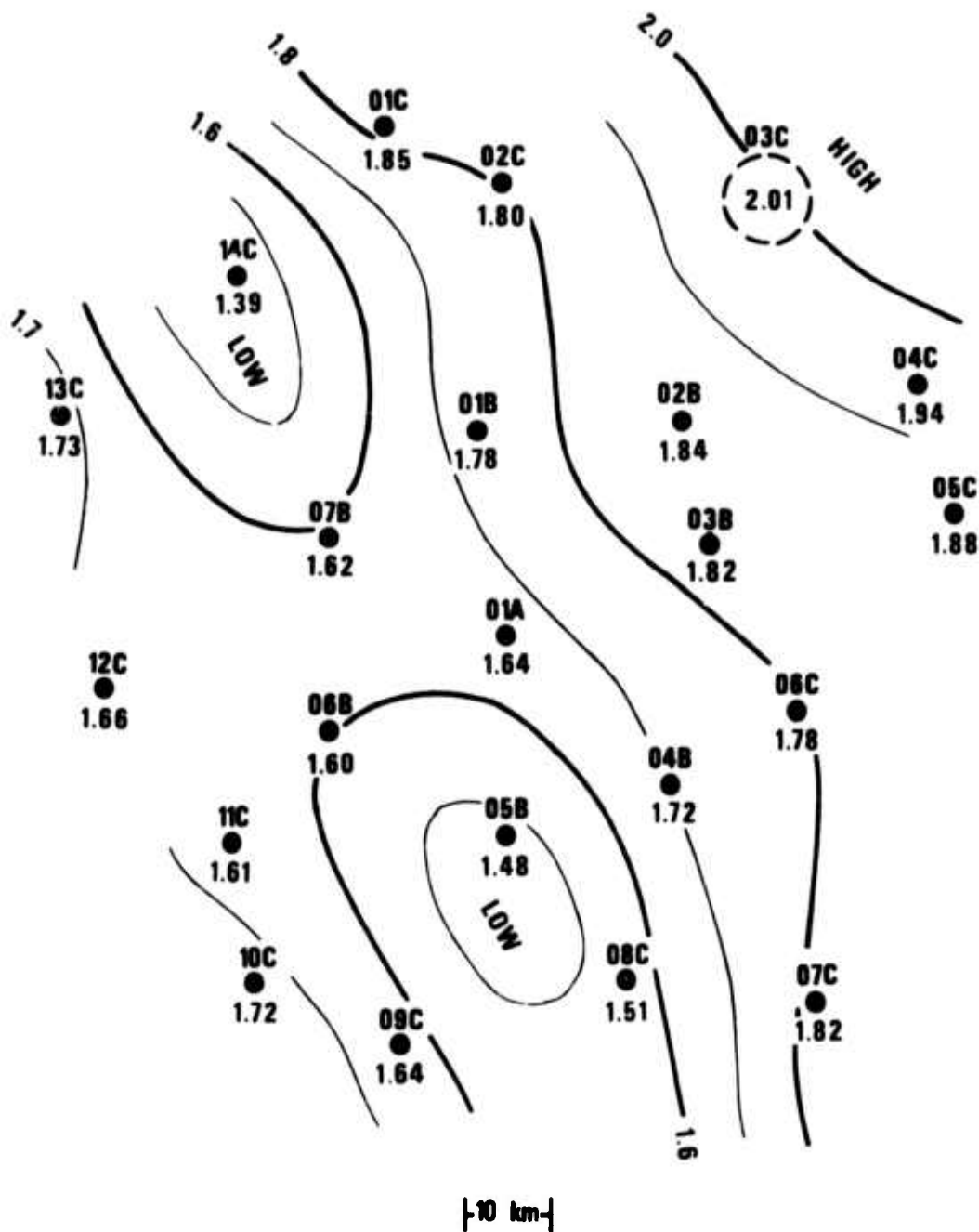


Figure 6. \log_{10} of signal-to-noise ratio $(O-P)/rms$ averaged over events in Table I at each subarray.

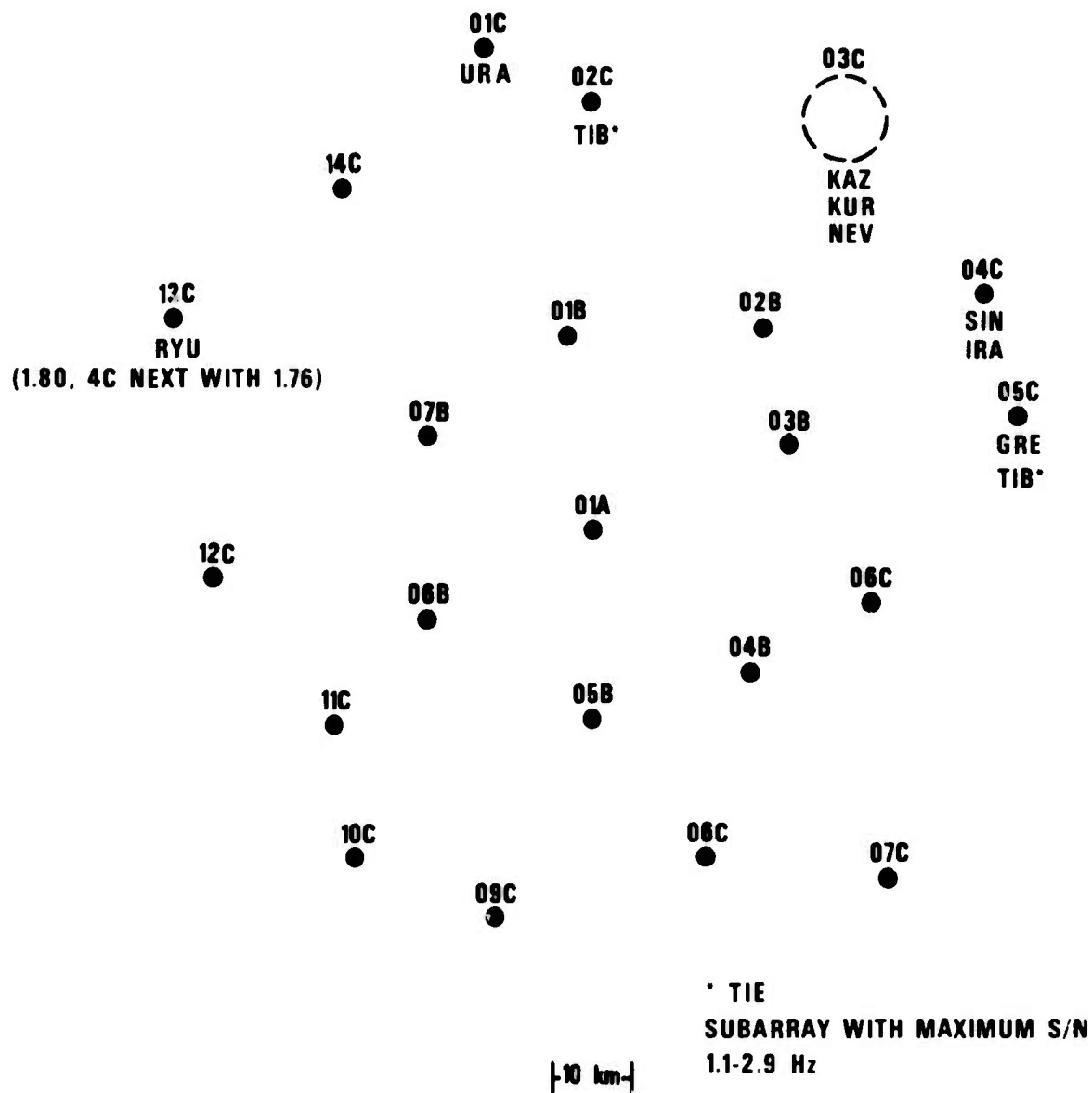


Figure 7. Subarray with maximum S/N for the events in Table I.

13C is best. However, it is only 0.04 magnitude units better than subarray 4C. This shows explicitly that the superiority of the northeast subarrays is not due to a very large superiority on a few events, but that it is a general phenomenon.

The general results found in Figure 5 are similar to those found by Felix, Gilbert, and Wheeler (1971) and by LaCoss and Filson (1972). Inspection of Figures 8 and 9, which have been drawn from data published by these authors, verifies that the highest signal levels are found in the northeast quadrant.

Figure 10 (from Berteussen, 1974) shows that the variability in travel time residuals as a function of azimuth is a minimum for subarrays 2C and 3C. This suggests that the geologic structures are smooth and regular under these subarrays. This may offer some explanation for their high signal amplitudes. Berteussen, Ringdal and Whitelaw (1973) attempted to explain respectively the travel time residual and amplitude data on the basis of an irregular Mohorovicic discontinuity. All solutions in Berteussen (1974) show a relatively flat interface under 2C and 3C. However, crustal measurements by Kanestron and Haugland (1971) as reported by Ringdal and Whitelaw show a sloping interface under 2C and 3C.

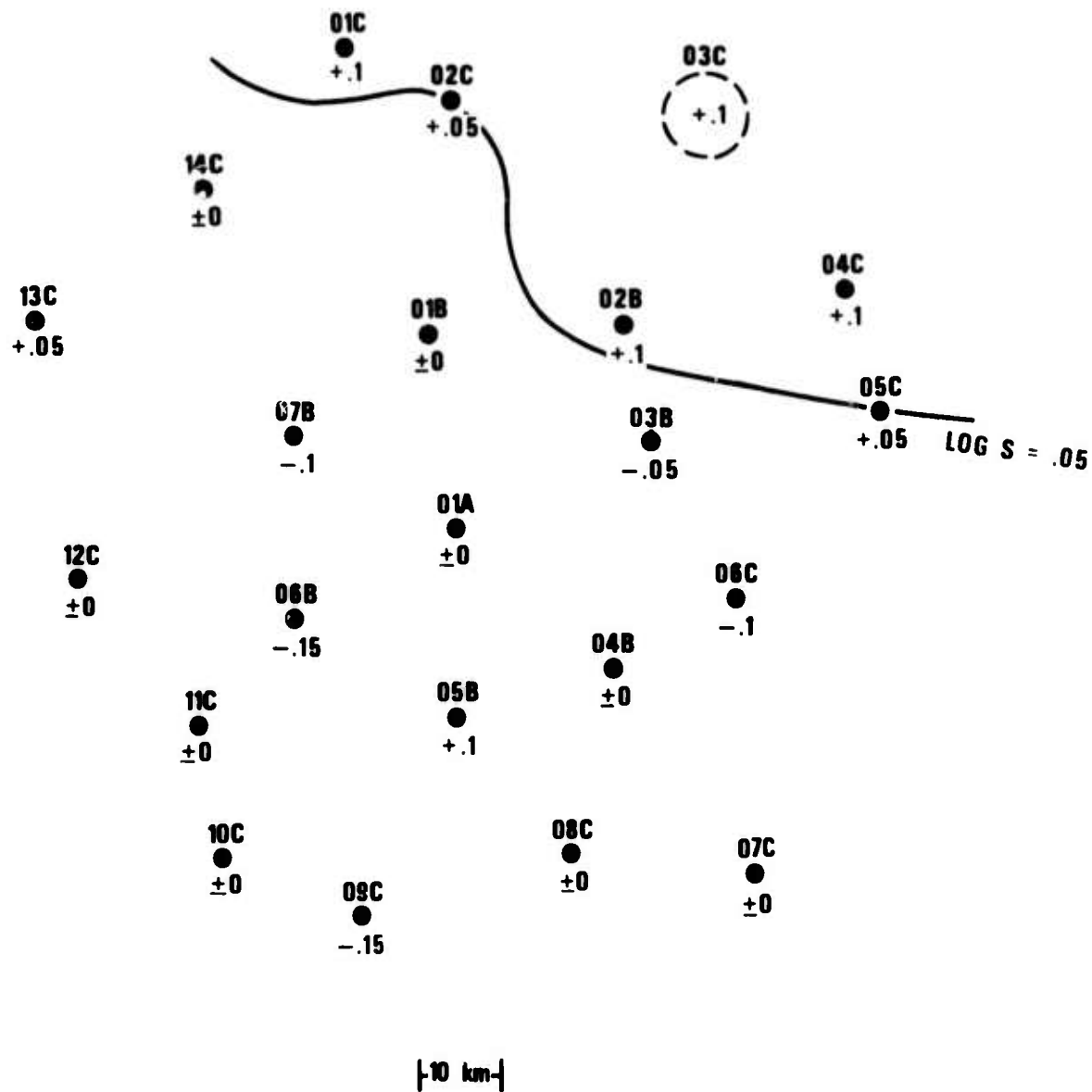


Figure 8. Average relative subarray signal amplitudes in magnitude units. Data taken from Figure 9a, Felix, et al. (1971).

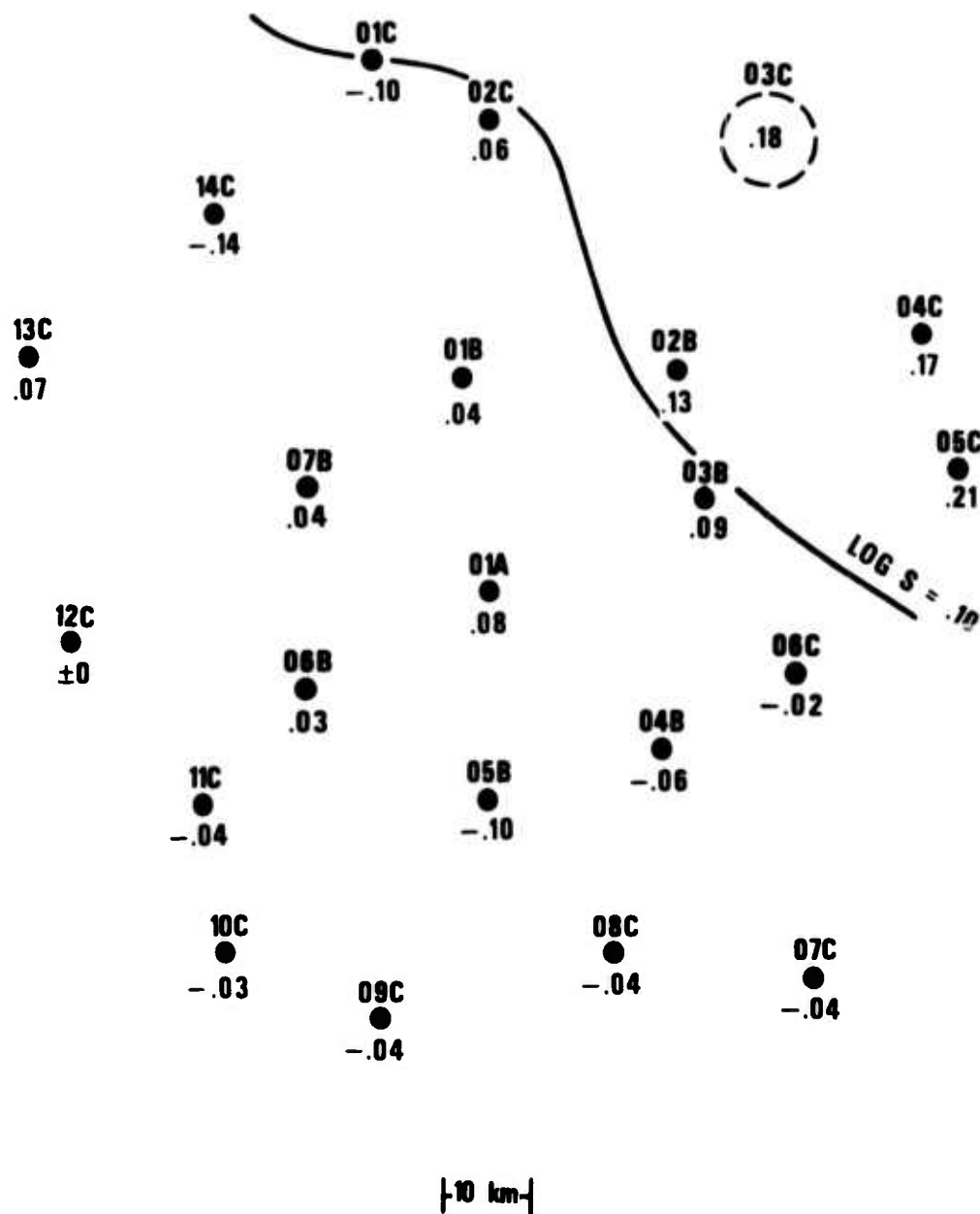


Figure 9. Amplitude anomalies in magnitude units from 16 regions. Data taken from LaCoss and Filson (1972) Table IV-1. (In this study the workers averaged normalized amplitudes instead of log amplitudes.)

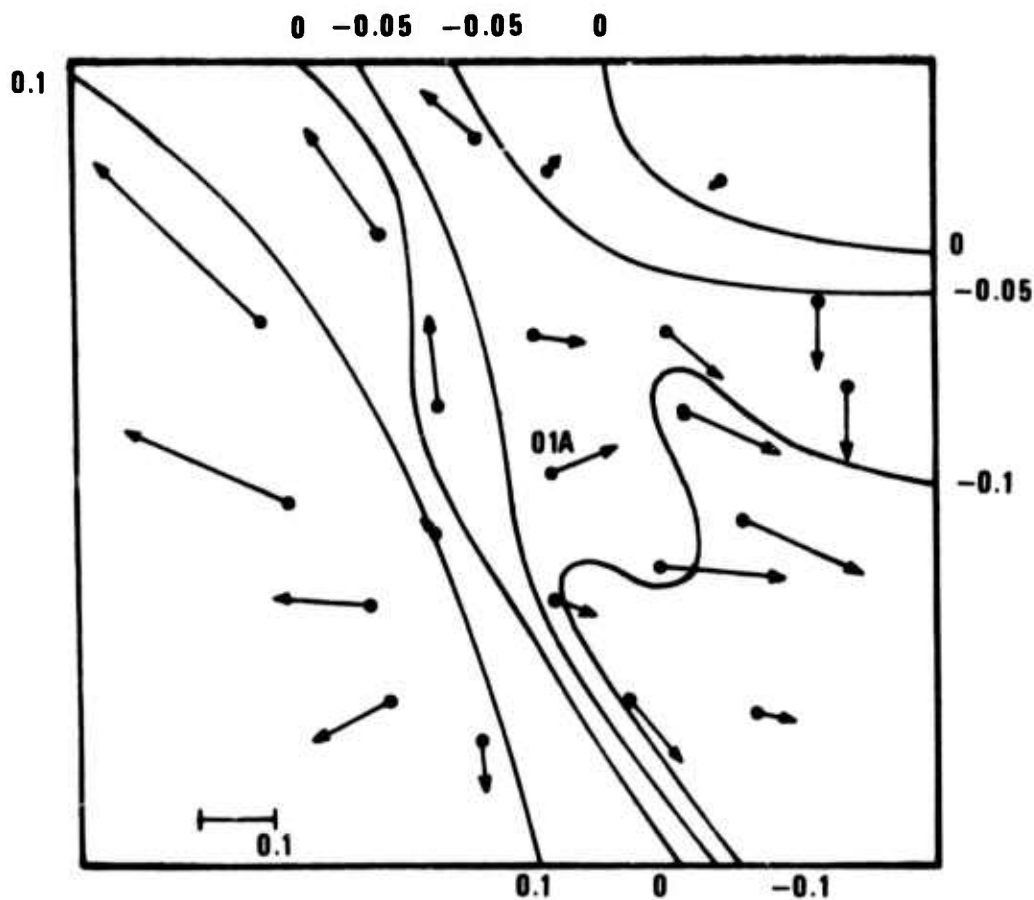


Figure 10. Length of arrow is proportional to B in the equation: $\text{Relative Residual} = A + B\sin\theta$ where θ is the azimuth to the event. From Berteussen (1974).

SIGNAL TO NOISE RATIOS FROM FULL AND PARTIAL ARRAY BEAMS

To beamform the full array it is necessary to use travel times that are corrected to the world-wide average tables. While it would be possible to align the subarray beams precisely for these large events, such a procedure would not be a test of the array's operational capability. In routine operations it is necessary to use a fixed set of residuals, and if the signal-to-noise improvement obtained with that set is not sufficient for detection, then the event is not detected. Any further improvement which would in principle be possible for that event is almost academic. An exception to this would be if an event is detected by other means at a site very close to a calibration event. Then the precise residuals for that calibration event might be used for the new event. In general it will be necessary to use tabulated corrections for routine operations.

The most comprehensive table of such corrections for NORSAR is that published by Berteussen (1974); they may also be found in Anonymous (1973). This table is constructed as follows: A set of one or more calibration events is found for each of 104 nodes in velocity space. The known geographic locations of these calibration events correspond via a known world-wide travel time table to a location in velocity space (UCX, UCY). Each calibration event will also have an observed location in velocity space (UX, UY) which is obtained for each calibration event by fitting a plane wave to the arrival times. The residuals from this plane wave are referred to as the regional corrections.

To determine the appropriate delays for the events in Table I we first found the closest node in (UCX, UY) space. Then the vector difference between the location of the event in (UCX, UCY) space and the location of the node was applied as a correction to the location of the node in (UX, UY) space to give the location of the event in (UX, UY) space. Finally, we used the regional corrections of the nearest node. Note that no elevation corrections are required since they are absorbed in the regional corrections.

The delays $D(I)$ are computed in accordance with the formulas from Berteussen (1974):

$$D(I) = DPWF(I) - DEV(I)$$

$$DPWF(I) = -(X(I) \cdot UX + Y(I) \cdot UY).$$

$D(I)$ is the delay for the 0 element of the I th subarray, $DPWF$ is the moveout appropriate to the location of the event in slowness space, X and Y are the location of the 0 element, and DEV are the regional corrections. In application of these formulas to QUICSAN it is important to remember that all time delays must be positive; and that the delay for a subarray beam must be that for the element of the subarray at which the signal first arrives. The delays are calculated by program DELAY.

In Table III we see the logarithms of the signal, noise, and signal-to-noise for the full array beam; a partial array beam consisting of the 10 subarrays 1-4B and 1-6C; and subarray 3C alone.

We note that the average signal level is .15 magnitude units higher for the 10-subarray beam, and .43 magnitude units higher for subarray 3C. The noise level is .21 magnitude units higher, and .59 units higher respectively. The net result is a loss in S/N of .06 and .18 magnitude units respectively.

This last result implies that if the 3C subarray were expanded to 14 elements its detection performance would equal that of the full array. Carrying this one step further, a 3C subarray of 56 elements would have a detection threshold 0.3 magnitude units lower than the present NORSAR. With hexagonal spacing at 2 km such an array would have a diameter of 15 km.

To analyze the question of whether direct summation infinite velocity subarray beams would be appropriate for NORSAR we evaluated the average $\log_{10} (S/N)$ for infinite velocity beams of subarray 3C. The answer, 1.56, is .45 m_b units below the phased subarray beam average of 2.01 seen in Table III.

In this analysis we included the two close-in events from the Urals and Greece, URA and GRE, at distances of 20 and 23 degrees. As would be expected, the travel time residuals and signal correlation between subarrays are poor for these events. Thus the expanded 3C array should be even more superior for these events. However, excluding these events results

TABLE III

Array Beam Signal, Noise, and S/N for Beams of 22,10 Northeast, and 1(3C) Subarrays. Values are \log_{10} of the maximum O-P signal or rms Noise in mμ.

EVENT	S-22	N-22	S/N-22	S-10	N-10	S/N-10	S 3C	N 3C	S/N 3C
KAZ/145/04N	1.37	-1.0	2.37	1.59	-.79	2.38	1.79	-.42	2.23
RYU/240/15N	.95	-.90	1.84	1.16	-.69	1.85	1.46	-.25	1.71
URA/191/16N	1.35	-1.00	2.36	1.71	-.77	2.48	2.04	-.34	2.38
IRA/221/02N	1.55	-.78	2.44	1.59	-.49	2.28	1.57	-.33	1.90
TIB/123/00N	1.60	-1.0	2.60	1.70	-.69	2.38	1.84	-.25	2.09
KUR/213/02N	1.63	-.95	2.61	1.74	-.91	2.65	2.07	-.48	2.55
SIN/207/01N	1.67	-.63	2.30	1.71	-.38	2.11	2.09	.02	2.07
NEV/230/14N	.65	-.94	1.59	.79	-.75	1.54	1.20	-.38	1.58
GRE/109/02N	.87	-.70	1.58	.96	-.57	1.53	1.49	-.09	1.58
Average	1.29	-.88	2.19	1.44	-.67	2.13	1.72	-.29	2.01
Observed Δm_b				+1.15	+2.21	-.06	+4.43	+5.59	-.18
Expected if 0 signal loss and \sqrt{N} for noise				0	+1.17	-.17	0	+6.67	-.67
Average Neglecting URA and GRE	1.34	-.88	2.25	1.46	-.67	2.13	1.72	-.30	2.02
Observed Δm_b Neglecting URA and GRE				+1.12	+2.21	-.06	+4.43	+5.58	-.23

in no significant change in the averages. Some of the loss of detection capability of the full array for regional events is presently recovered in practice at NORSAR by incoherent beamforming; see for example Ringdal, Husebye and Dahle, 1972; and Blandford and Wirth, 1973.

Table IV shows that the average noise reduction by the full array beam, and by the 10-subarray beam, with respect to the average individual sensor noise level, is proportional to the square root of the total number of sensors in the beam. The signal loss for teleseismic events with respect to individual sensors is 4.9 and 4.2 dB respectively; and the signal-to-noise ratio gain is 16.0 and 12.4 dB respectively.

These results on signal-to-noise ratio improvement could conceivably be misleading if the signal-to-noise ratio were distributed log-normally, as numerous investigators have shown to be the case at LASA and NORSAR, and if the variance at NORSAR were especially large. This would be true, because if the variance were large, the upper tail of the log-normal distribution would heavily weight the "average" S/N ratio. The average would then be much higher than the value of the median or typical subarray which is the measure of improvement most in accord with the question, "What is the improvement of a large array over a typical small array?".

To examine this problem we constructed Table V which shows the standard deviation in magnitude units of signal, noise and S/N among individual elements for the 10 events. We see that for teleseismic events the signal loss relative to the average individual sensors is 4.9 dB using an arithmetic average, and 3.6 dB using a logarithmic average. The difference, 1.3 dB, would not be significant in most practical array or network design problems.

As a side light it is surprising that the two regional events have the smallest standard deviation for the signal, even though we saw in Table IV that the array beam signal loss is large for these events due to poor signal correlation. Perhaps this shows that the regional signals are so thoroughly diffused that the average maximum amplitudes are more stable than they are for more vertically arriving rays in which sharp focusing and defocusing effects are predominant.

TABLE IV

Array Beam Signal Loss, Noise Reduction, And S/N Gain
in dB for Arrays of 22 and 10 Northeast Subarrays.

EVENT	22				10			
	$\frac{-dB}{\sqrt{N}}$	N -dB Obs	S -dE Obs	S/N dB Obs	$\frac{-dB}{\sqrt{N}}$	N -dB Obs	S -dB Obs	S/N dB Obs
KAZ/145/04N	21.2	22.8	3.2	19.0	17.6	17.8	1.9	15.6
RYU/240/15N	21.0	20.8	6.9	13.5	17.5	16.2	4.1	11.7
URA/191/16N	21.1	21.5	15.7	5.5	17.6	16.4	9.0	7.2
IRA/221/02N	21.1	21.6	5.6	15.6	17.5	17.1	5.3	11.5
TIB/123/00N	21.1	23.1	2.8	19.9	17.6	16.4	2.4	13.6
KUR/213/02N	21.1	19.4	3.8	14.7	17.6	17.0	3.9	13.7
SIN/207/01N	21.1	22.1	5.0	17.1	17.6	17.6	5.7	11.8
NEV/230/14N	20.9	20.0	7.2	12.9	17.1	15.5	5.9	10.1
GRE/109/02N	20.9	19.1	13.3	5.4	17.6	16.1	13.1	2.7
Average	21.1	21.0	7.0	13.7	17.5	16.7	5.7	10.8
Average Teleseismic Neglecting URA and GRE	21.1	21.0	4.9	16.0	17.5	16.7	4.2	12.4

TABLE V

Standard Deviation in Magnitude Units of Signal, Noise and S/N among all individual seismometers at the array. Also, for both the normal and log-normal distributions the loss of signal for the full array beam over either individual elements or individual subarrays.

EVENT	σ_{m_b}			Signal Loss Over Individual Elements		Signal Loss Over Individual Elements in dB for 22 Subarray Beam		Signal Loss Over Individual Subarrays in dB for 22 Subarray Beam	
	S	N	S/N	normal	log-normal	normal	log-normal	normal	log-normal
KAZ/145/04N	.28	.10	.30	3.2	1.3	1.3	- .8	1.3	- .8
RYU/240/15N	.21	.15	.21	6.9	5.8	5.1	4.1	5.1	4.1
URA/191/16N	.15	.10	.15	15.7	15.2	12.7	12.4	12.7	12.4
IRA/221/02N	.19	.15	.14	5.6	4.8	3.8	3.3	3.8	3.3
TIB/123/00N	.24	.09	.26	2.8	1.4	1.6	.2	1.6	.2
KUR/213/02N	.25	.23	.29	3.8	2.3	2.7	1.4	2.7	1.4
SIN/207/01N	.36	.26	.18	5.0	3.6	3.4	2.6	3.4	2.6
NEV/230/14N	.28	.20	.18	7.2	5.7	5.3	4.0	5.3	4.0
GRE/109/02N	.14	.09	.17	13.3	12.8	11.3	10.8	11.3	10.8
Average	.23	.15	.19	7.0	5.9	5.2	4.2	5.2	4.2
Average Neglecting URA and GRE	.26	.17	.20	4.9	3.6	3.3	2.1	3.3	2.1

SUMMARY AND DISCUSSION

- Noise levels vary across the array by 0.1-0.2 magnitude units and seem to be correlated with the level of cultural activity.

- High signal levels from events at all azimuths are recorded by the northeast subarrays.

- The northeast subarrays have high S/N ratios.

- An array of 10 northeast subarrays has only .06 magnitude units less detection capability than the full array.

- The 3C subarray alone has only 0.18 magnitude units less detection capability than the full array.

- If the 3C subarray were expanded to a 56 element, 15 km diameter array with 2 km spacing, its detection threshold would be 0.3 magnitude units lower than the present full array. Such a small array would require much less computer power for analysis than does the full array and would better preserve the high-frequency energy which may be useful for discrimination purposes. A possible method of implementation would be to move the equipment from existing southwest subarrays into sites around subarray 3C.

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